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Naval Ordnance Test Station
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A PRELIMINARY STUDY OF THE EFFECT OF THE FREE SURFACE ON A THREE-DIMENSIONAL CAVITY PRODUCED BY A CIRCULAR DISK

E. R. Bate, Jr.

Hydrodynamics Laboratory
Karman Laboratory of Fluid Mechanics and Jet Propulsion
California Institute of Technology
Pasadena, California

Report No. E-118.15

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Approved by: A. J. Acosta

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NOMENCLATURE

Symbols	Definition	Units
d	Disk diameter	Inches
h	Submergence of disk center below the free surface	Inches
$K = \frac{P_o - P_K}{1/2 \; \rho \; U^2}$	Ventilation number	Dimensionless
ℓ	Cavity length	Inches
P_K	Cavity pressure	Pounds/feet^2
P_o	Free stream pressure	Pounds/feet^2
U	Free stream velocity	Feet/second
ρ	Density of water	$\frac{\text{Pound Second}^2}{\text{Feet}^4}$

Introduction

The influence of the free surface on the cavitation associated with bodies operating at shallow submergences has long been of interest because of the practical use for such information. The performance of hydrofoil boats is very much dependent on the submergence below the water surface of the hydrofoils, for example.

Because of the extreme complexity introduced by the consideration of boundaries of any sort, most theories relating the parameters associated with cavitation are developed for a fluid of "infinite" extent. The task of determining the effects of the boundaries for such a cavitating flow problem then becomes one of experimentation. Such an experiment was performed to determine the free surface effects on a supercavitating, flat plate hydrofoil in two-dimensional flow [1*].

However, most real flow situations are three dimensional, and the present experiment is a preliminary study to determine the effects of the free surface on the geometry of a ventilated cavity in such a flow. Specifically, the variation of the length of a cavity due to submergence is studied. The cavity is produced by a sharp-edged, circular disk normal to the flow. Figures 1a and 1b show this cavity at two different ventilation numbers.

This experiment was planned as a preliminary study to determine the general trend and order of magnitude of the free surface effects. For this reason, the results are presented with the preliminary data reduced to the pertinent dimensionless parameters, uncorrected for tunnel blockage and model scale effects, if any.

Experimental Procedure and Equipment

The experiment was performed in the Hydrodynamics Laboratory of the California Institute of Technology, in the Free-Surface Water

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* Super scripts refer to references at the end of this text.

Tunnel. Figure 2 shows the general experimental arrangement, and a view of the tunnel working section with the model installed can be seen in Figure 3.

The models used were two disks, one inch and two inches in diameter, respectively. Each model was attached to the end of a hollow sting. The sting was supported from an aluminum strut which had a 21 per cent thickness ratio. The strut was hollow and had a 4 inch chord with a symmetrical circular arc cross-section and rounded leading and trailing edges. It is a standard Alcoa extruded section No. 76761. Figures 5a and 5b show both models and stings attached to the strut. The hollow spaces in the sting and the strut served as passages for supplying cavity air and containing the tubing which led to the cavity pressure tap. The strut was attached to an elevating mechanism which allowed the model to be raised or lowered and hence its depth beneath the free surface could be varied.

Air was supplied to the cavity through holes drilled in the sting just downstream of the disk. An annular brass shield was placed around the sting above these holes so that the air blast from them would be deflected and would not deform the walls of the cavity. The air flow rate was not measured.

Cavity pressure was measured by means of a water U tube manometer. The pressure side of the manometer was connected to the pressure tap in the cavity. The pressure tap was a 1/16 inch diameter brass tube which projected into the cavity from the sting. The other leg of the manometer was open to the atmosphere.

In order to insure that the pressure tap would remain free from water droplets, air was bled slowly through the cavity pressure line from a "tee" fitting located near the manometer. This air flow through the connecting line and the pressure tap produced an initial pressure drop which had to be subtracted from the cavity pressure readings as a tare correction. The value of this tare pressure was kept constant by adjusting the air flow before each cavity pressure reading was made to

the value which existed when the system was calibrated. A diagram of the cavity pressure measuring system can be seen in Figure 6.

Cavity lengths were determined by visually comparing the end of the cavity with a scale that was held against the lucite window of the tunnel working section. To eliminate parallax, a flashlight was held directly beneath the observer's eye when a reading was made. The observer moved axially along the tunnel until the reflection of this light in the lucite window was aligned with the end of the cavity. The cavity length was then determined by the location of the reflection of the light with respect to the scale. Figure 4 shows a cavity length measurement being made.

A problem encountered in making the cavity length measurement involved deciding what constituted the end of the cavity. All of the cavities were viewed from the side and regardless of the type of cavity closure (re-entrant jet or trailing vortices), they all had a small area composed of a frothy mixture of air and water at their immediate ends (see Figs. 1a and b). This frothy area was defined as the cavity end, and all measurements were made to this point.

The flow in the vicinity of the end of the cavity was quite turbulent, producing a great deal of oscillation of the cavity. This oscillation also gave rise to difficulties in measuring the cavity lengths. At best, the cavity length data can probably be considered accurate to within $\pm$ 1 inch.

Discussion of Results

Figures 7 and 8 show the results in the form of cavity length-to-disk diameter ratios plotted against ventilation number for several values of submergence-to-disk diameter ratios. At a given ventilation number, the effect of the proximity of the free surface is to decrease the cavity length.

Waid[2] has also conducted an experimental program in the Free-Surface Water Tunnel in which the geometry of a cavity produced by a circular disk was determined. From the data which was obtained, an empirical equation was developed which relates the cavity half-length to

the ventilation number (Reference (2), Equation 4). This equation (multiplied by two to convert cavity half-length to total cavity length) has been presented along with the data from the present experiment in Figures 7 and 8. Waid's data was all taken at a constant submergence of 8 inches, but the models used varied in diameter from 1 inch to 1/2 inch. Hence the submergence ratios obtained in his experiment varied from 8.0 to 16.0.

The data obtained in the present experiment shows longer cavity lengths at equivalent ventilation numbers and submergence ratios than the curve obtained by Waid. This is true for both of the disks tested except for the 1 inch disk at a cavity length ratio below 15. Below this value, the cavity was short enough that the pressure field associated with the support strut was able to affect the flow near the end of the cavity. This produced a shorter cavity than would have been obtained if the strut were absent. During the testing, it was noticed that as the air supply was increased to change the size of the cavity, the end of the cavity tended to "stick" at the position of the strut until the air supply had been increased sufficiently, at which time the cavity would "spring" downstream.

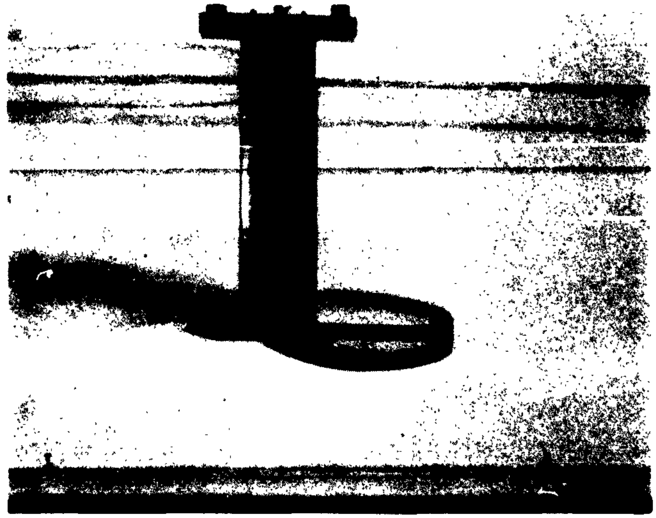
A comparison between the data obtained with the 2 inch disk and the 1 inch disk in the present experiment shows that the cavity length ratios are larger for the 2 inch disk at equivalent submergence ratios and ventilation numbers. This result, as well as the disagreement between this experiment and Waid's can probably be explained by tunnel blockage. The increased velocity in the vicinity of the cavity due to the flow blockage caused by the cavity itself would result in reduced ventilation numbers. This would give rise to a cavity length which was longer than one produced by a ventilation number based on the free stream velocity.

The Froude number range in the present experiment (Fr = 6 to 16) was sufficiently close to the range of Waid's experiment (Fr = 7 to 20), that Froude number effects are probably not an important cause for the disagreement between the two experiments.

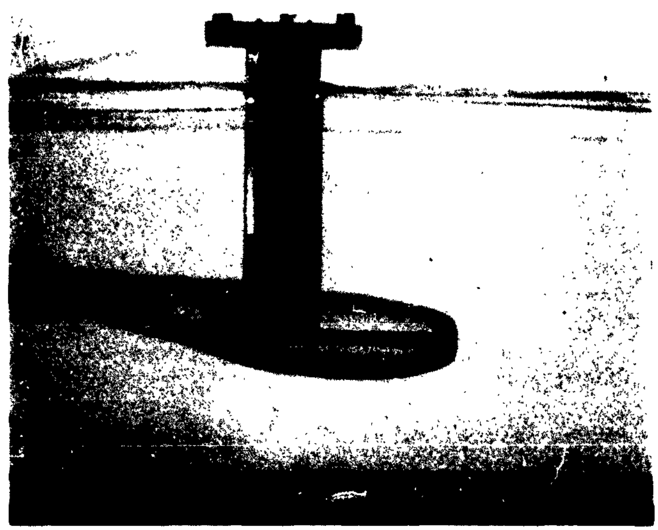
REFERENCES

1. Dawson, T.E. and Bate, E.R.Jr., "An Experimental Investigation of a Fully Cavitating Two-Dimensional Flat Plate Hydrofoil Near a Free Surface", California Institute of Technology, Hydrodynamics Laboratory, Report E-118.12, October, 1962.

2. R. L. Waid, "Cavity Shapes for Circular Disks at Angles of Attack", California Institute of Technology, Hydrodynamics Laboratory, Report E-73.4, September, 1957.

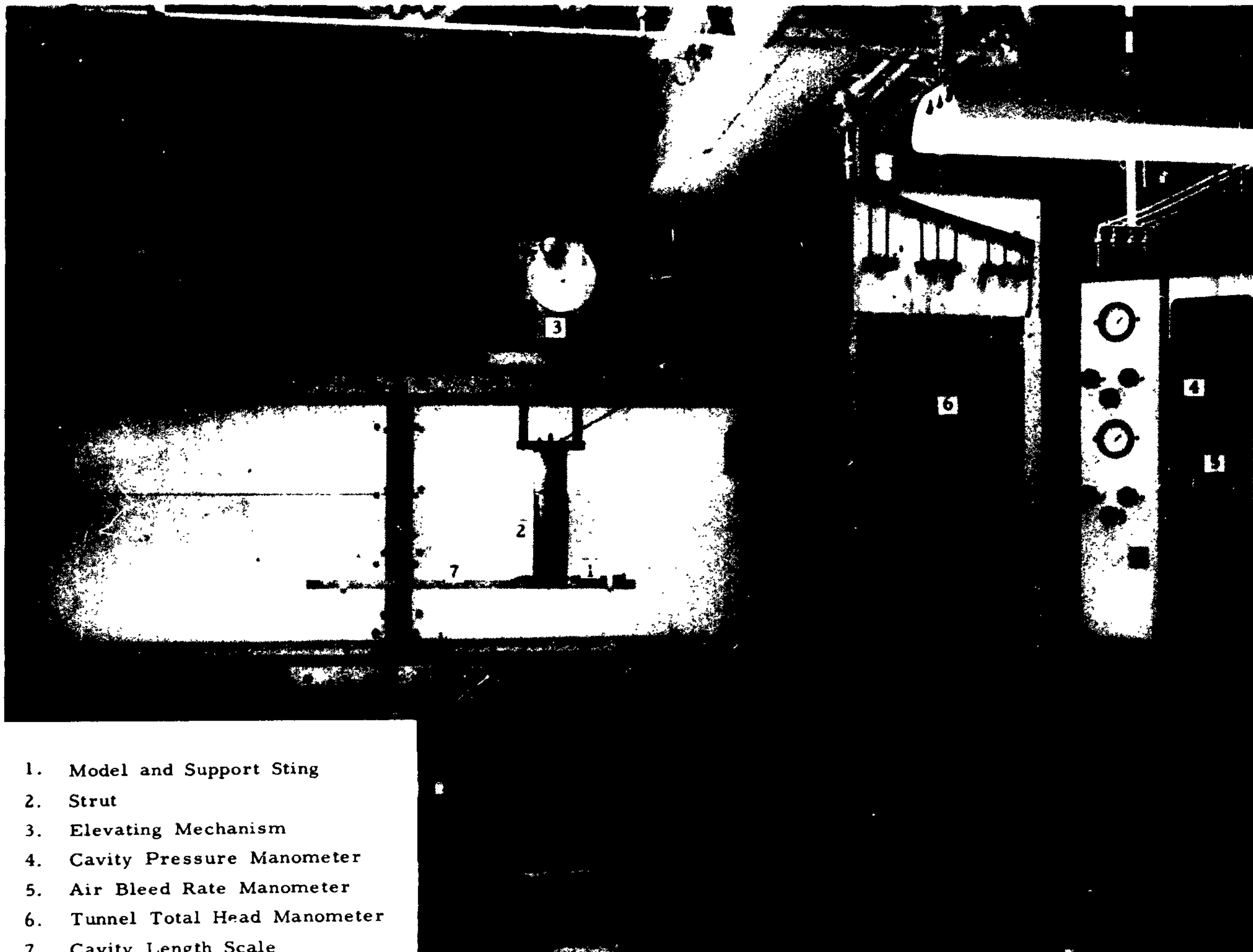


a. Re-entrant Jet Cavity Closure.



b. Trailing Vorticies.

Fig. 1 - Cavities Produced by 2 Inch Diameter Disk.
Submergency = 12 Inches, Velocity = 14 ft/sec.



1. Model and Support Sting
2. Strut
3. Elevating Mechanism
4. Cavity Pressure Manometer
5. Air Bleed Rate Manometer
6. Tunnel Total Head Manometer
7. Cavity Length Scale

Fig. 2 - View of Experimental Facilities.

Fig. 3 - 2 Inch Diameter Disk Mounted in Water Tunnel Working Section.

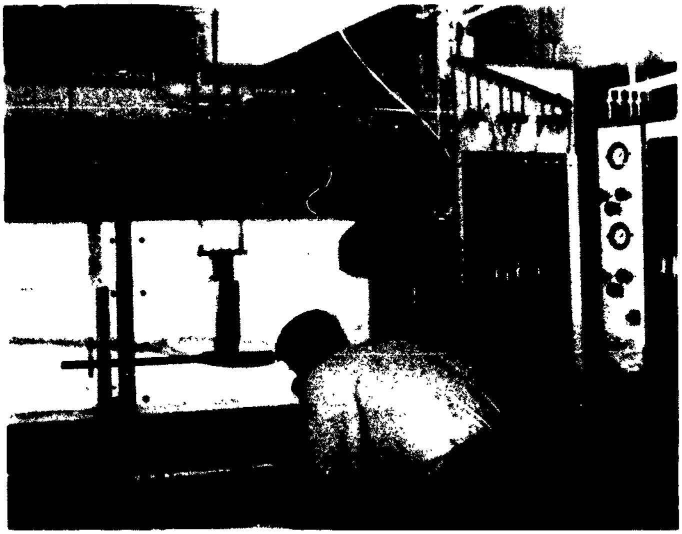
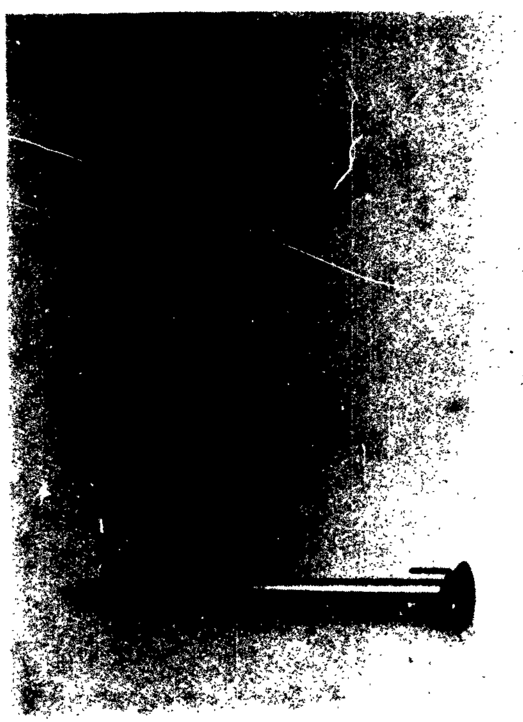


Fig. 4 - View of Test Facility Showing Experimental Cavity Length Measurement being made.



a. 2 Inch Diameter Disk.

b. 1 Inch Diameter Disk.

Fig. 5 - Models Shown Mounted to Strut and Stings.

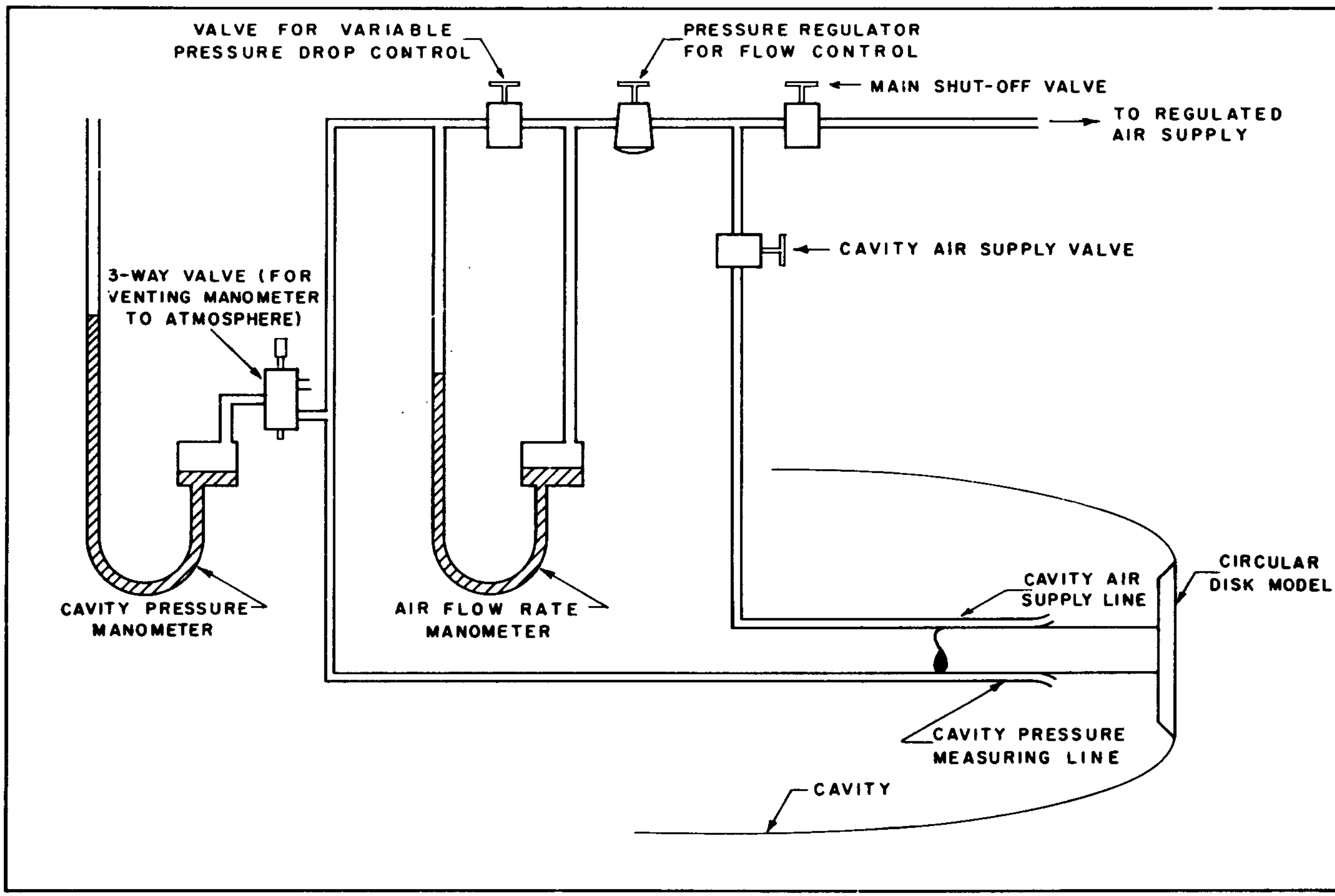


Fig. 6 - Diagram of Cavity Pressure Measuring System.

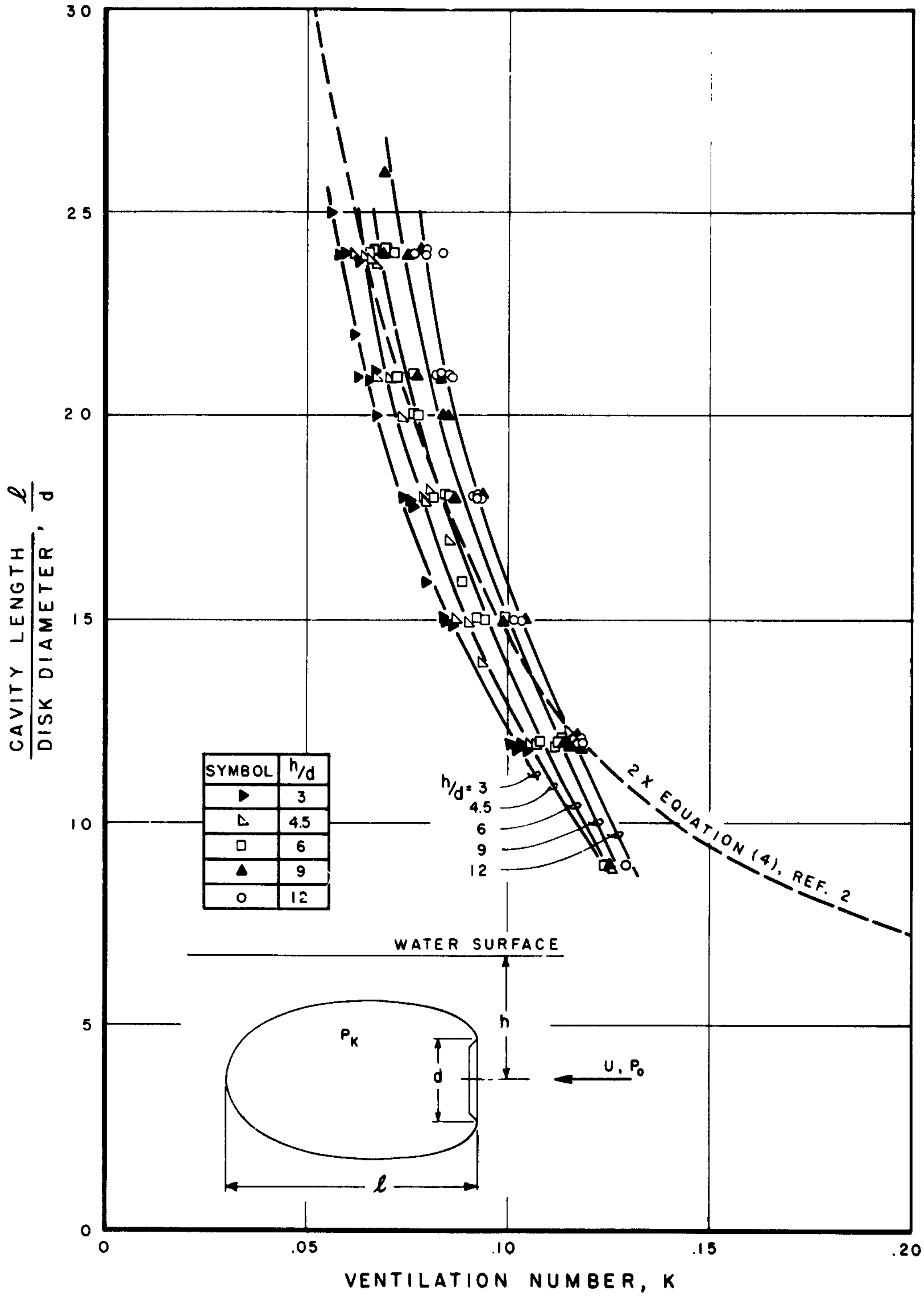


Fig. 7 - Cavity Length as a Function of Ventilation Number for the 1 Inch Diameter Disk.

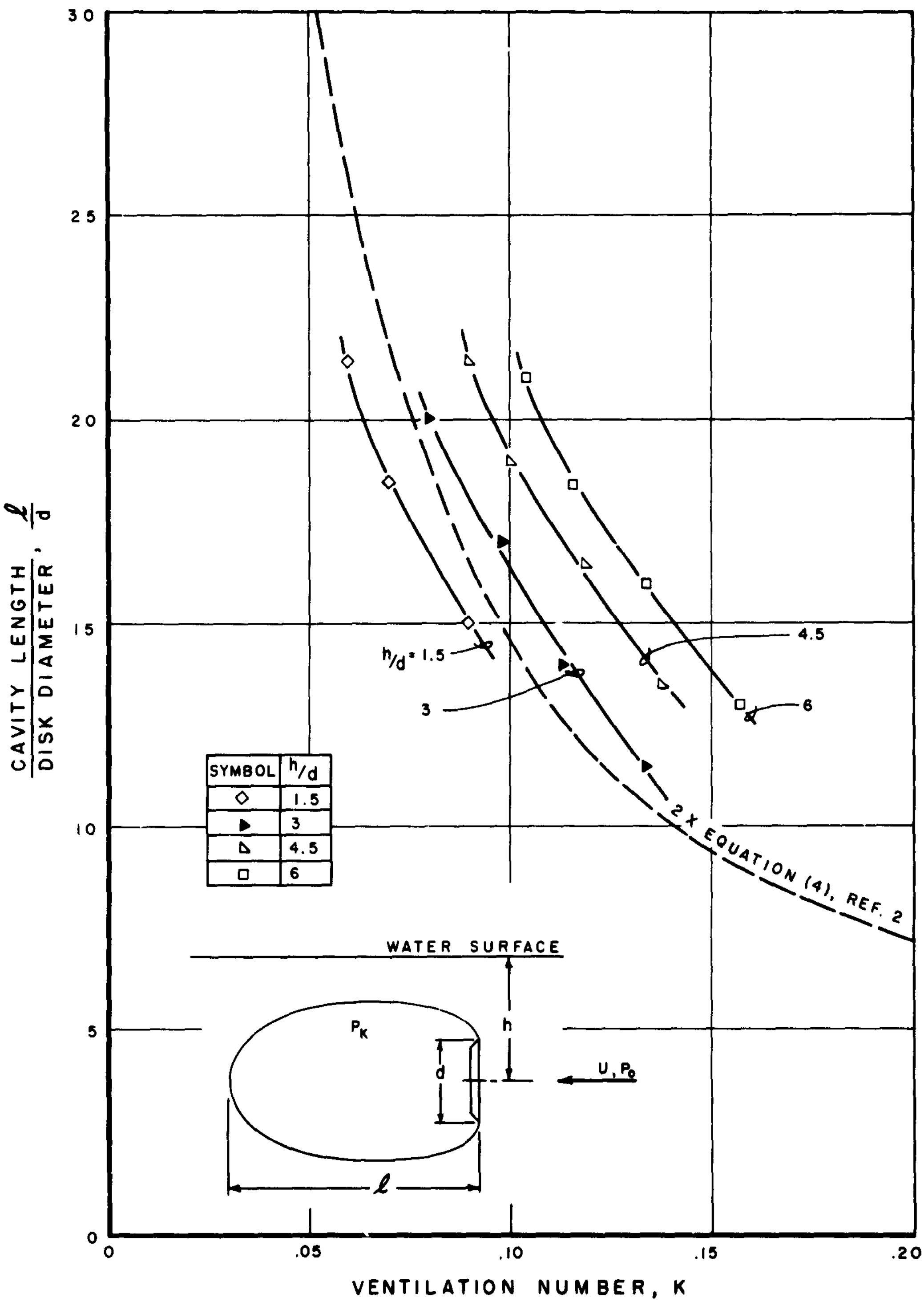


Fig. 8 - Cavity Length as a Function of Ventilation Number for the 2 Inch Diameter Disk.

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